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Procedia Computer Science 73 (2015) 426 – 434
Procedia Computer Science

The International Conference on Advanced Wireless, Information, and Communication Technologies (AWICT 2015)

UAV Channel Estimation with STBC in MIMO Systems

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Abstract

The combination of coding with spatial diversity opens up new dimensions in wireless communications with emphasize to Unmanned Aerial Vehicles (UAVs), and can offer effective solutions for wireless communication channels. Application of Alamouti Space-Time Block Codes (STBCs) with diversity with multiple antennas provide improved performance in faded wireless channels. Alamouti transmit diversity scheme, however, relies on the availability of accurate Channel State Information (CSI). This paper proposes a channel estimation method based on Kalman filter with STBC codes and multiple antenna systems, namely Multiple-Input Single-Output (MISO) and Multiple-Input Multiple-Output (MIMO) systems. Simulations have been done in time-varying Rayleigh faded channels for BPSK and QPSK. The proposed technique seems to obtain an error performance closer to that of a known channel information case in severely faded channel considerations.

Peer-review under responsibility of organizing committee of the International Conference on Advanced Wireless, Information, and Communication Technologies (AWICT 2015)

Keywords: Signal to Noise Ratio, Doppler Shift, Radio Propagation; SNR, MIMO, STBC, Estimation

1. Introduction

In wireless radio channels, a signal from the transmitter may arrive at the receiver antenna through several different paths. The transmitted electromagnetic wave may be reflected, diffracted, and scattered by surrounding buildings and the objects in the way of radio communications, UAVs radio links are suitable example for kind of multipath fading channels. As a result, the signal picked up by the receiver antenna is a composite signal consisting of these multipath signals. Sometimes a Line-of-Sight (LoS) signal may exist. The multipath signals arrive at the receiver at slightly different delays and have different amplitudes. Space-time Block Codes (STBC) is a method that

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Peer-review under responsibility of organizing committee of the International Conference on Advanced Wireless, Information, and Communication Technologies (AWICT 2015)
doi:10.1016/j.procs.2015.12.019

receiver usually employed into radio systems to improve the reliability of data transmission using multiple antennas[1,2]. The overall performance can be further enhanced if the assistance of channel estimation is considered. In this paper, a pilot symbol assisted channel estimation technique using Kalman filter is used to estimate the channel. Kalman filter, together with orthogonally assigned known pilot symbol placement, promises to raise the BER performance with insignificant loss in the data transmission rate[5,9].

1.1. Maximum Likelihood

In this paper, a linear Maximum Likelihood (ML) decoder that works under the assumption of time-invariance over one STBC is used for Kalman filter and in symbol decoding. Simulation results obtained illustrate an error performance closer to that of a known channel information case in Rayleigh faded channel considered for both BPSK and QPSK modulation schemes respectively[3,4].

1.2. Paper organization

This paper is organized into the following sections. Section 2 presents an insight into STBC-MIMO System and fading channel characteristics considered for the proposed work. Section 3 describes the channel estimation technique using Kalman Filter. Section 4 describes the system model for STBC coded MISO-MIMO in multipath fading channel. Our results are included in Section 5. Finally Section 6 concludes the paper.

2. Considerations of STBC and Multiple Antenna Systems

To improve the spectrum efficiency/capacity, coverage of wireless networks, and link reliability, Space-Time wireless technology that uses multiple antennas. Space-time block codes have a most attractive feature of the linear decoding/detection algorithms and thus become the most popular among different STC techniques. The use of STBC and MIMO has proven to be an effective combination. This section provides a brief description of STBC, MIMO and related channel aspects considered for the work[7].

The radio channel places fundamental limitations on the performance of wireless communication systems. The transmission path from the transmitter to receiver can vary from simple line-of-sight to one that is severely obstructed by buildings, mountains, cars and trees. In wireless communication, radio waves are mainly affected by three different modes of physical phenomena: Reflection, Diffraction, and Scattering so in the considerations should take them as important components into account[6].In wireless communications systems, each of the multipath components have different relative propagation delays and attenuations which results in filtering type of effect on the received signal.

Unique characteristic in a wireless channel is a phenomenon called fading, the variation of the signal amplitude over time and frequency. Fading describes the rapid fluctuations of the amplitudes, phases or multipath delays of a radio signal over a short period of times or travel distances[1]. For vehicular radio channels, there is also the Doppler frequency shift. Doppler shift causes carrier frequency drift and signal bandwidth spread. All these matters cause degradation in performance of modulation schemes in comparison with that in AWGN channels. Now an introduction to fading is described.

In a slow fading channel, the channel impulse response changes at a much slower rate than the symbol rate. The channel coherence time is much greater than the symbol duration, or equivalently, the Doppler spreading is much smaller than the signal bandwidth[7,8].

If the channel impulse response changes rapidly within signal symbol duration, the channel is classified as a fast fading channel, otherwise it is classified as a slow fading channel. The fast change of the channel impulse response is caused by the motion, or equivalently, the Doppler spreading. Quantitatively when the channel coherence time is smaller than the symbol duration, or equivalent, the Doppler spreading is greater than the signal bandwidth, a signal undergoes fast fading.

Flat fading is also called Frequency nonselective fading. If a wireless channel has a constant gain and linear phase response over a bandwidth which is greater than the signal bandwidth, then the signal will undergo flat or frequency nonselective fading. This type of fading is historically the most common fading model used in the literature.

In flat fading, the multipath structure is such that the spectral characteristics of the transmitted signal is preserved at

the receiver [5,6].
The complex coefficient defines the phase shift and power attenuation produced by the scatterer. In this case there receiver, receives a number of rays equal to the number of scatterers plus the LoS ray that connects directly the transmitter to the receiver. For the transmitted signal s(t) we have:

$$s(t) = \mathrm{Re}\left[s_l(t) e^{j2\pi f_c t} \right] \tag{1}$$

Where $s_l(t)$ is baseband signal:

$$x(t) = \sum_n \alpha_n(t)\, s[t - \tau_n(t)] \tag{2}$$

x(t) in the received signal and $\alpha_n(t)$ is the attenuation factor for the signal received on the *n*-th path with propagation delay, $\tau_n(t)$. Substituting (1) into (2), we obtain:

$$x(t) = \mathrm{Re}\left(\left\{ \sum_n \alpha_n(t) e^{-j2\pi f_c \tau_n(t)} s[t - \tau_n(t)] \right\} e^{j2\pi f_c t} \right) \tag{3}$$

Where $r_l(t)$,the baseband complex-valued signal is:

$$r_l(t) = \sum_n \alpha_n(t) e^{-j2\pi f_c \tau_n(t)} s[t - \tau_n(t)] \tag{4}$$

Consequently the equivalent baseband complex impulse response of the time varying multipath channel:

$$c(\tau; t) = \sum_n \alpha_n(t) e^{-j2\pi f_c \tau_n(t)} \delta[\tau - \tau_n(t)] \tag{5}$$

The received signal may be described as:

$$x(t) = \int_{-\infty}^{\infty} \alpha(\tau; t) s(t - \tau) d\tau \tag{6}$$

Where $\alpha(\tau; t)$ is the attenuation of the signal components with delay τ and at time *t*. By replacing $s(t)$ in (6) with respect to (1), we obtain the received signal equation:

$$x(t) = \mathrm{Re}\left\{ \left[\int_{-\infty}^{\infty} \alpha(\tau; t) e^{-j2\pi f_c \tau} s_l(t - \tau) d\tau \right] e^{j2\pi f_c t} \right\} \tag{7}$$

Therefore the baseband impulse response of the channel is:

$$c(\tau; t) = \alpha(\tau; t) e^{-j2\pi f_c \tau} \tag{8}$$

Where $c(\tau; t)$ represents the response of the channel at time *t* due to an impulse applied at time $t - \tau$ [6,12].The spatial diversity, also called Antenna Diversity is a simple, efficient and widely used technique applied to reduce the negative effects of multipath fading environments from many scatterers. The diversification of space is to use multiple antennas transmitting and / or receiving stations, which are located some distance from each other that the different versions of the signal arriving at each of the receive antennas to be subject to different fading. In such a way that the quality the Bit Error Rate (BER), for each user is improved. The core idea in MIMO transmission is space-time signal processing in which signal processing in time is complemented by signal processing in the spatial dimension by using multiple, spatially distributed antennas at both link ends. MIMO systems are composed of three main elements, namely the transmitter (Tx), the channel (H), and the receiver (Rx).The channel with N outputs and M inputs is denoted as a $M \times N$ matrix:

$$\mathrm{H} = \begin{pmatrix} h_{11} & \cdots & h_{1N} \\ \vdots & \ddots & \vdots \\ h_{M1} & \cdots & h_{MN} \end{pmatrix} \tag{9}$$

where each entry h_{ij} denotes the attenuation and phase shift (transfer function) between the i^{th} transmitter and the j^{th}

receiver. The MIMO signal model is described as, $\vec{r} = H\vec{s} + \vec{n}$, where r is channel matrix of size M×N, s is the transmitted vector of size M×1, and n is the noise vector of size N×1. Each noise element is typically modelled as independent identically distributed (i.i.d.) white Gaussian noise with variance N_t/ (2×SNR). A MIMO system with M transmit antennas and N receive antennas has potentially full diversity (i.e. maximum diversity) gain equal to MN.
One of the methodologies for exploiting the capacity in MIMO system consists of using the additional diversity of MIMO systems, namely spatial diversity, to combat channel fading. This can be achieved by transmitting several replicas of the same information through each antenna. By doing this, the probability of losing the information decreases exponentially[6,10].

2.1. Space Time Block Coding-STBC

The STBC is widely used technique in wireless communications for transmitting different copies of information from multiple antennas and the use of different versions of the same information to the receiver in such a way as to improve the system performance. The space-time coding basically combines (combining) all copies of the original signal, obtained in the most appropriate manner in order to recover from them the best possible information. The space-time coding is usually denoted by a symbol table. Each series represents a time (timeslot), in which the transmitted symbol and each column the number of transmitting antennas which send symbols for time [1, T]. The block of symbols is the set of symbols that are transmitted from all the antennas the period T. Each modulated symbol s_{ij} denotes the symbol sent at time i from antenna j. For example, the element of the second row and third column of the matrix, s_{23} ,is the symbol transmitted from the third antenna to the second time duration of the block[11,13].

2.2. Alamouti space-time Block code

Assume a telecommunications system with two transmitting and one receiving antenna. Two signals are emitted simultaneously from both antennas at a given time and encoded in space-time, as shown below:
The block symbols take two moments. The first time emitted the modulated symbols s_0 and s_1 and second symbols $-s_1^*$ and s_0^* , Where the "*" denotes the conjugate of a complex number.
It is considered that the channel at time t is defined fading with $h_0(t)$ for the first antenna and $h_1(t)$ for the second antenna. Assume the fading is constant during two consecutive symbols, and the duration of a symbol is obtained:

$$\begin{aligned} h_0(t) &= h_0(t+T) = h_0 = a_0 e^{j\theta_0} \\ h_1(t) &= h_1(t+T) = h_1 = a_1 e^{j\theta_1} \end{aligned} \tag{10}$$

The signals received at the time points t and (t+T) are:

$$\begin{aligned} r_0 &= r_0(t) = h_0 s_0 + h_1 s_1 + n_0 \\ r_1 &= r_1(t+T) = -h_0 s_1^* + h_1 s_0^* + n_1 \end{aligned} \tag{11}$$

With n_0 and n_1 symbolized the noise at the receiver as complex random variable. Then create the following signals to the linear receiver (combiner) and sent to the maximum likelihood detector (maximum likelihood detector):

$$\begin{aligned} \tilde{s}_0 &= h_0^* r_0 + h_1 r_1^* \\ \tilde{s}_1 &= h_1^* r_0 - h_0 r_1^* \end{aligned} \tag{12}$$

Substituting the relations for r_0 and r_1 finally obtained:

$$\begin{aligned} \tilde{s}_0 &= (a_0^2 + a_1^2)s_0 + h_0^* n_0 + h_1 n_1 \\ \tilde{s}_1 &= (a_0^2 + a_1^2)s_1 - h_0 n_1^* + h_1^* n_0 \end{aligned} \tag{13}$$

In some applications, it is desirable greater diversity gain is possible application of the Alamouti code for two transmitting antennas and M receive antennas, thus ensuring diversity gain 2xM. Below is the case of the 2x2 system, which generalizes easily to 2xM. Define tables H and R:

$$H = \begin{pmatrix} h_0 & h_2 \\ h_1 & h_3 \end{pmatrix}$$
$$R = \begin{pmatrix} r_0 & r_2 \\ r_1 & r_3 \end{pmatrix} \tag{14}$$

The element of the first row and the second column is the intermittency factor of the channel between the first transmitting antenna and the second receiving antenna. The table represents the received by the two antennas signals during the two moments which is the period of the block symbols[12]. The matrix of transmission is same as the case 2x1:

$$S = \begin{pmatrix} s_0 & s_1 \\ -s_1^* & s_0 \end{pmatrix} \tag{15}$$

Finally, apply the received signals:

$$\begin{aligned} ro &= h_0 s_0 + h_1 s_1 + n_0 \\ r1 &= -h_o s_1^* + h_1 s_0^* + n_1 \\ r2 &= h_2 s_0 + h_3 s_1 + n_2 \\ r3 &= -h_2 s_1^* + h_3 s_0^* + n_3 \end{aligned} \tag{16}$$

Where n_o, n_1, n_2, n_3 are complex-valued random variables representing receiver noise and interference. The linear receiver generates the following signals, which are then sent to the maximum likelihood detector[6,13]:

$$\begin{aligned} \hat{s}_o &= h_o^* r_o + h_1 r_1^* + h_2^* r_2 + h_3 r_3^* \\ \hat{s}_1 &= h_1^* r_0 - h_0 r_1^* + h_3^* r_2 - h_2 r_3^* \end{aligned} \tag{17}$$

Substituting r_0 and r_1 in the above relations follows:

$$\begin{aligned} \hat{s}_o &= (a_0^2 + a_1^2 + a_2^2 + a_3^2)s_0 + h_0^* n_0 + h_1 n_1^* + h_2^* n_2 + h_3 n_3^* \\ \hat{s}_1 &= (a_0^2 + a_1^2 + a_2^2 + a_3^2)s_1 - h_0 n_1^* + h_1^* n_0 - h_2 n_3^* + h_3^* n_2 \end{aligned} \tag{18}$$

These signals are easily detected by the receiver maximum likelihood, and the system performance 2xM. This is shown below where given in detail the results of simulations.

3. Channel Estimation

Kalman Filter is used for tracking MIMO channels based on a low order autoregressive (AR) model.

Estimation procedure: The Kalman filter estimates the state $x \in R^n$ of a discrete-time controlled process that is governed by the linear stochastic difference equation

$$x_k = Ax_{k-1} + Bu_{k-1} + w_{k-1} \tag{19}$$

with a measurement $z \in R^m$ that is

$$z_k = Hx_k + u_k \tag{20}$$

The random variables w_k and v_k represent the process and noise respectively. They are assumed to be independent of each other, and with normal probability distributions.

$$\begin{aligned} p(w) &\sim N(0, Q) \\ p(u) &\sim N(0, R) \end{aligned} \tag{21}$$

The $n \times n$ matrix A in the difference equation relates the state at the previous time step $k - 1$ to the state k at the current step. The $n \times l$ matrix B relates the optional control input $u \in R^l$ to the state x.

The state estimate at step k is defined as $\hat{x}_{\bar{k}} \in \mathbb{R}^n$ given knowledge of the process prior to step k, and $\hat{x}_k \in \mathbb{R}^n$ to be *a* post-prior state estimate at step k given measurement z_k. *a priori* and *a posteriori* estimate errors are

$$\bar{e}_k = x_k - \hat{x}_{\bar{k}} \tag{22}$$

$$e_k = x_k - \hat{x}_k \tag{23}$$

The prior estimate error covariance is then

$$\overline{P}_k = E[\overline{e}_k e_k^{\overline{T}}] \tag{24}$$

and the post-prior estimate error covariance is

$$P_k = E[e_k e_k^T] \tag{25}$$

A state estimate $\hat{x}_k$ can be computed as a linear combination of an a priori estimate $\hat{x}_{\overline{k}}$ and a weighted difference between an actual measurement z_k and a measurement prediction $H\hat{x}_{\overline{k}}$

$$\hat{x}_k = \hat{x}_{\overline{k}} + K(z_k - H\hat{x}_{\overline{k}}) \tag{26}$$

The difference $z_k - H\hat{x}_{\overline{k}}$ is called the measurement innovation, or the residual. The $n \times m$ matrix K is chosen to be the gain or blending factor that minimizes the *posterior* error covariance.

$$K_k = \overline{P}_K H^T (H\overline{P}_K H^T + R)^{-1} \tag{27}$$

After each time and measurement update pair, the process is repeated with the previous *a posteriori* estimates used to project or predict the new *a prior* estimates [6,11,14].

4. System Model for STBC Coded MISO-MIMO

The state space equations for tracking the MIMO channel can be expressed as:

$$\begin{aligned} h(t+1) &= A(t)h(t) \\ s(t) &= C(t)h(t) + u(t) \end{aligned} \tag{28}$$

where h is the channel tap, A is a time-varying transition matrix, C is the observation matrix and u is the measurement noise vector. On the receive antenna, the noise n has the Gaussian probability density function with:

$$p(n) = 1/\sqrt{2\Pi\sigma^2}\exp[-(n-\mu^2)]/2\sigma^2 \tag{29}$$

with $\mu_{hi,j} = 0$ and $\sigma_h{}^2{}_{i,j} = No/2$. A first-order Auto-Regressive (AR) model provides a sufficient model for time varying channels. Therefore, A can be a diagonal matrix of autoregressive model factor α, where

$$\alpha = E[h_{ij}(t+1) * h^*{}_{ij}(t)] \tag{30}$$

The Kalman filter equations for MIMO channel are divided into two parts. First part is the predictor:

$$\begin{aligned} \tilde{h}(t+1|t) &= A(t)\tilde{h}(t|t) \\ P(t+1|t) &= A(t)P(t|t)A^{*T}(t) \\ \varepsilon(t) &= s(t) - C(t)\tilde{h}(t+1|t) \end{aligned} \tag{31}$$

And the second part is the update:

$$\tilde{h}(t+1|t+1) = \tilde{h}(t+1|t) + K(t)\varepsilon(t) \tag{32}$$

Where, $R_u = \beta I$ and β is a covariance of the noise vector v. The K matrix is called the Kalman gain and the P matrix is called the estimation error covariance [6,15].

5. Simulation Results

In this section, simulation results and comparisons are presented. Table.1 shows simulations parameters.

Number of Pilot Subcarriers	Decoding Subcarrier per Subcarrier	8 Pilot Subcarriers
Tx=2 Rx=1	3.1s	0.48s
Tx=2 Rx=2	4.7s	0.6s
Tx=4 Rx=1	5.8s	0.69s
Tx=4 Rx=2	9.76s	1.2s

Table.1 Simulation parameters

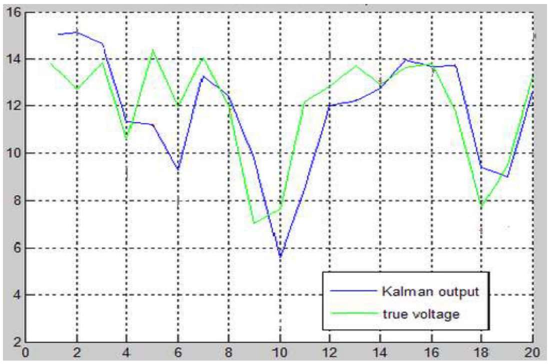

Fig .1. Tracking Performance of Kalman Filtering

Figure 1 shows the Kalman filter output it tracking the input signal with high accuracy.
The performance of the channel estimator based on Kalman filter is tested through simulations for both BPSK and QPSK modulation scheme in Rayleigh faded channel.

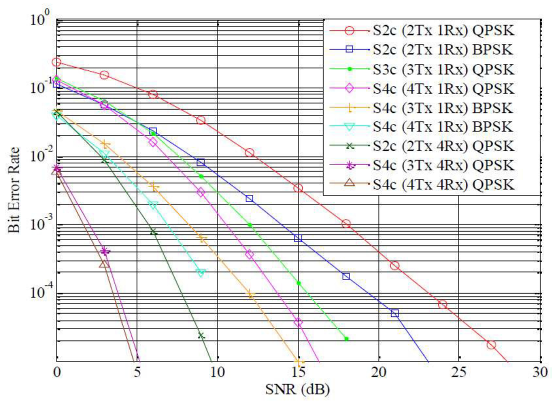

Fig .2. Channel estimated with Kalman filter STBC for BPSK and QPSK modulation

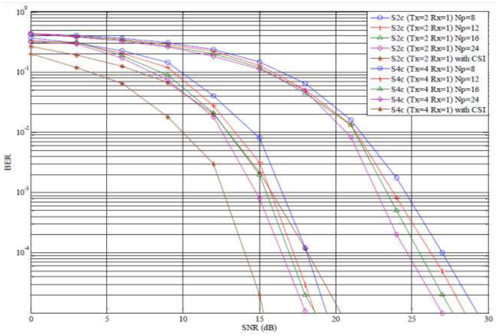

Fig.3. Channel estimated with Kalman for 2 and 4 Transmit Antennas with 1 Receive Antennas with STBC for BPSK and QPSK modulation

Error performances are measured as BER against the SNR values for both the cases of STBC coded MISO and MIMO with modulation schemes, namely BPSK and QPSK. Figures 2 and 3 show the BER result for channel estimated with Kalman filter algorithm and for known channel in MISO and MIMO system respectively.
The choice of modulation technique affects the performance of Kalman Estimator. Simulation results show that BPSK modulation scheme achieves better performance than QPSK in both multi antennas. The channel experienced by each transmit antenna is independent from the channel experienced by other transmit antennas. For the transmitter, each transmitted symbol gets multiplied by a randomly varying complex number hi,j . With the proposed iterative channel estimation technique, the grouping of symbols improves the computational efficiency of the system. When the number of pilot symbols increase, the number of groups also increases. Figures show where there is no relationship between the decoding time and the number of transmit antennas or number of pilot symbols and it is clear that the decoding time per symbol is reducing with the number of antennas.

6. Conclusion

A new channel estimation has been proposed for MIMO systems. Investigations of STBC-MIMO were first conducted and simulations results for different number of transmit and receive antennas were obtained. This work describes space-time coding for MISO and MIMO systems for use in wireless environment. The performance of space-time codes for wireless multiple-antenna systems with and without diversity in Rayleigh faded channel has been studied. BER performance is evaluated for receive diversity and transmit diversity techniques for BPSK and QPSK modulation systems. It is observed that enhancement in performance is obtained when STBC coding schemes are used in MIMO scheme, as compared to MISO and MRC schemes over the Rayleigh faded channel. MISO scheme shows a degraded result than the MRC scheme for both the cases. Moreover, since the knowledge of the channel with perfect CSI is unattainable for Alamouti STBC over Rayleigh fading channel which makes the error performance to degrade, a pilot based channel estimation technique is proposed. STBC achieves full diversity but full rate only for the case of two transmit antennas, while QOSTBC achieves both full rate and full diversity for two and four transmit antennas. However, decoding complexity of QOSTBC grows exponentially with the number of antennas used, whereas STBC decoding complexity grows linearly with the number of transmit and receive antennas.

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